THE EFFECT OF MIXING SPEED AND DRY MILK SOLIDS ON BREAD

by

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INTRODUCTION

A problem which confronts the baker who uses dry milk solids is the effect of mixing speeds on the baking quality of doughs. According to Mr. Roud McCann[1], the personnel of the bakery service department of the American Dry Milk Institute have noticed instances of less satisfactory results from doughs mixed at high speeds which were corrected by longer mixing at reduced speeds.

A brief study of the problem by Myers[2] indicated that a poorer loaf of bread resulted from decreasing the speed of mixing normally used in the experimental laboratory. It, thus, appeared possible that what had been termed a high speed in the experimental laboratory had been, from the standpoint of net effect, a comparatively slow speed. The findings of Myers, coupled with the unsatisfactory commercial results from high speed mixers, as stated above, suggested the desirability of trying optimum mixing speeds.

Preliminary trials in the present study on the effect of mixing speed on bread containing dry milk solids indicated that optimum speeds could be found for the various amounts of dry milk solids present. Preliminary studies also indicated that, for loaf volume, there was an optimum dry milk solids content for bread.

The term "dry milk solids" has been used throughout this study to mean dried skim milk solids with a fat content not exceeding 1.5 percent and a maximum water content of 5.0 percent.

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[1] Personal communication from Mr. Roud McCann, director of the American Dry Milk Institute; May, 1941.

[2] Unpublished data from research problem regarding mixing speeds. Department of Milling Industry, Kansas State College; 1941.

The object of this investigation was to determine the optimum mixing speeds for various dry milk solids contents and to determine the optimum dry milk solids content of bread.

REVIEW OF LITERATURE

Bohn and Bailey (1936) found that excessive mixing of a dough beyond optimum development produced inferior bread, and that high speed mixers developed dough more quickly than low speed mixers. Stamberg and Bailey (1938) found optimum mixing times for each speed of rotation of the mixing blades. They also noted that the inclusion of six percent dry milk solids in bread dough increased the mixing time and increased the tolerance to variation in mixing speed. The optimum speed of mixing for the Hobart-McDuffee mixer was found, by them, to be between 60 and 80 revolutions per minute.

Larmour and MacLeod (1929) studied the effect of potassium bromate on wheat flours. They found that a bromate formula gave a better measure of baking value than the basic formula. Geddes and Larmour (1933) studied some aspects of the bromate baking test and found that the bromate formula gave better measurements of the relative flour strength than the basic formula. They also noted that bromate response was somewhat dependent upon the protein content. This would indicate the presence of optimum bromate requirements for flours.

Ofelt and Larmour (1940) studied the buffering effect of dry milk solids toward bromate and found that the addition of dry milk solids created a tolerance to potassium bromate which tends to prevent damage to loaf volume and to grain and texture when large dosages of this reagent are used. According to Ofelt and Larmour, dry milk solids, together with appropriate amounts of potassium bromate, produce increases in loaf volumes and improvements in texture beyond that which could be obtained with bromate alone.

Barmore, Finney, and McCluggage (1941, 1942) reported the effect of potassium bromate on bread doughs. They demonstrated the presence of an optimum bromate requirement for flours from various varieties. According to them, the optimum bromate requirement varied with flours from different varieties.

During the planning and execution of this study, special attention was paid to the procedures used to obtain the data and to the mathematical techniques needed to properly evaluate such data. The propriety of taking these precautions is illustrated by the following citations.

Pearson (1930), in writing of the phenomenon of variation as depicted by the normal curve, quoted Francis Galton, an early statistician, thus:

> I know of scarcely anything so apt to impress the imagination as the wonderful form of cosmic order expressed by the law of error. It would have been personified by the Greeks and deified, if they had known of it. It reigns with severity in complete self-effacement amidst the wildest

> confusion. The huger the mob and the greater the anarchy the more perfect is its sway. Let a large sample of chaotic elements be taken and marshalled in order of their magnitudes and then, however widely irregular they appear, an unexpected and most beautiful form of regularity proves to have been present all along.

Pearson also discussed the theory of correlation as the result of the limitations of the theory of causation which was used extensively by scientists of the past. In correlation it is recognized that result A may well be caused by more than one factor, whereas the causation theory did not. The correlation coefficient is the square root of the fractional part of A caused by the factor being considered. Much like the mean, the correlation coefficient increases in reliability as the number of observations increase.

In 1932 Goulden wrote:

> In cereal chemistry experiments, the analysis of variance seems to be particularly applicable, as there is a definite experimental variability which cannot be overcome by methods now in use; and the sorting out of this variability and allocating it to different sources is often the most serious problem with which the cereal chemist has to deal in generalizing from his results.

In accordance with these views arrangements were made for obtaining adequate data with a minimum of routine effort.

MATERIALS AND METHODS

Three flours and three mixing machines were used. The flours were obtained from Tenmarq and Chiefkan wheats and a commercially blended wheat mix from a Kansas flour mill.

The three mixing machines used were the Working, the Swanson-Working, and the Hobart-McDuffee. The mixing action of the Working mixer was produced by a two-arm planetary mixing head and three stationary arms. This mixer was a newly designed model and, while usable for its specific purpose, was not suitable for the range of conditions imposed upon it by this investigation. The Swanson-Working mixer had a four-arm planetary mixing head and two stationary arms. The Hobart-McDuffee machine was equipped with a two-arm planetary mixing head and one stationary arm.

Mixing speeds of 50, 75, 100, 125, 150, 175, and 200 revolutions per minute were used on the Working and Swanson-Working mixers, while 40, 70, 100, and 130 revolutions per minute were used on the Hobart-McDuffee mixer. The mixing effects of the 40 to 130 RPM range on the Hobart-McDuffee mixer approximately equaled the mixing effects of the 50 to 200 RPM range on the other mixers.

A commercial-type formula with the following constituents per loaf of bread was used: 100 g flour, 6 g sugar, 1.5 g salt, 3 g shortening, 2 g yeast, 0.25 g malt syrup (120° Lintner), variable amounts of potassium bromate, and water as needed. To this formula was added dry milk solids in amounts of zero, two, six, 12, and 20 percent. This type of formula simulates those of commercial bakeries and also tends to reduce the variations in grain and texture; thus, the loaf volume variations become more significant. This was desirable because loaf volume was the only characteristic which could be measured mechanically.

Table 1 gives the average chemical analyses of the flours and dry milk solids used throughout the study.

In order to obtain similar handling properties, the absorption was increased with increased amounts of dry milk solids. The most suitable increases in absorption were curvilinearly related to the increases in dry milk solids; i. e., less water per percent dry milk solids was added at the 12 percent dry milk solids level than at the six percent level, etc. The dry milk solids used in this study had a lower water absorbing ability than was normal.

Twenty percent dry milk solids was added to only one flour. This was discontinued and ignored in the mathematical work because it was found to be beyond the practical limits of dry milk solids content for bread. Bread produced with the addition of 20 percent dry milk solids had a cheese-like flavor, very fine grain, and a heavy rubbery texture. The loaf volume of bread containing 20 percent dry milk solids was considerably less than for six or 12 percent dry milk solids content. Whereas, the loaf volumes of both the six and 12 percent dry milk solids bread were usually greater than the bread without dry milk solids.

Seven flour-mixer groups of data were obtained. These groups, their mean loaf volumes, and their mean variances are given in Table 2.

Within each of these seven groups the data were arranged according to combinations of mixing speeds and dry milk solids content. In each group there were four levels of dry milk

Table 1. Chemical analyses of the materials used (data given as received).

Material	Protein* (percent)	Moisture* (percent)	Ash* (percent)
Dry milk solids	30.80	3.50	7.930
Tenmarq flour	12.24	11.39	0.495
Chiefkan flour	12.86	11.74	0.430
Commercial wheat mix flour	12.03	11.93	0.492

*The above results are averages of several samples drawn randomly at various times during the investigation.

Table 2. Mean loaf volumes and mean variances of the flour-mixer groups.

Flour-mixer group	Mean loaf volume (cc)	Mean variance *
Tenmarq flour, Working mixer	794	255.5
" " , Swanson-Working mixer	754	46.4
" " , Hobart-McDuffee "	769	191.0
Chiefkan flour, Swanson-Working "	680	24.3
" " , Hobart-McDuffee "	687	19.7
Commercial blend flour, Swanson-Working mixer	800	136.1
Commercial blend flour, Hobart-McDuffee "	727	15.6

*Snedecor (1941).

solids content. Seven different speeds of the Working and Swanson-Working mixers were studied as were four speeds of the Hobart-McDuffee mixer. Thus, there were 28 combinations of speeds and dry milk solids within four of the flour-mixer groups and 16 combinations within three of the flour-mixer groups - a total of 160 combinations of mixer, flour, speed, and dry milk solids.

Twelve replications were baked of each of the 160 combinations studied. This was done to obtain more reliable data and to more closely confine the variations of the phenomena. Thus, 1920 loaves of bread were used as experimental data. In addition, about 1500 loaves were baked to determine the optimum mixing times and optimum bromate requirements and to test the yeast used for each bake. After the optimum mixing time and optimum bromate requirement for each combination had been determined, they were held constant for their particular combination throughout the study. The elimination of these factors as variables reduced the amount of work involved about 80 percent.

The following procedure was used to determine the optimum mixing time for each combination. A dough which was the same as actually used for the thesis data was mixed to the estimated optimum dough development. The estimate was made by observing the dough while being mixed. Dough which is not developed is short and appears jagged. Dough which is overdeveloped becomes shiny and sticky. At optimum development the dough is smooth, has a velvety feel and is not sticky. Accordingly, when the dough appeared developed, the mixing time was noted. The dough was then removed from the mixer and handled as usual in the fermentation and proofing cabinets and in the oven.

Immediately following the first estimate, two other doughs of exactly the same formula and dry milk solids content were mixed approximately three-fourths and five-fourths of the estimated mixing time and also handled like an ordinary dough.

The loaf volume of each loaf of bread was taken immediately after baking and the grain and texture were noted the following day. No scoring of the grain and texture was done in this study. The internal characteristics were merely inspected to make sure that all data were obtained from loaves with grain and texture at least equal to the standards of commercial bakeries. If the internal characteristics of any loaf were unsatisfactory the particular dough combination that loaf represented was rebaked. The optimum mixing time was selected by measurement of the loaf volumes. If the estimated optimum mixing time was not found to be correct, the particular dough combination was retested according to the indications of the first test. Approximately one-third of the tests were repeated. All loaves were baked in duplicate during each test. In the same manner, the optimum bromate requirement for each flour and each dry milk solids content was determined.

The absorption was determined by means of the Mixograph (Swanson-Working Dough-recording Mixer) and the handling properties of the doughs. The flour was first mixed to test for handling properties. It was then mixed in the Mixograph and the height and shape of the mixogram noted. The absorption of the milk-containing flour-doughs was increased until they were the same height as the no-milk doughs. The shape of the mixograms change with the addition of dry milk solids.

On the basis of the above procedures, it was assumed that an optimum loaf of bread was produced in each combination.

Low-form, commercial-shaped pans were used throughout the investigation. Fermentation temperature and humidity were maintained at 30° centigrade and 75-80 percent respectively. Fermentation, punching, proofing, and baking were according to the official A. A. C. C. methods. Loaf volumes were taken immediately after baking and grain and texture noted the following day.

Split-loaf mixing was used on the Swanson-Working and the Hobart-McDuffee mixers. Because of limited capacity, single-loaf mixing was used on the Working mixer. All doughs were scaled to 172 grams immediately after being mixed. This was done to overcome the effects of increased dough weight due to the addition of dry milk solids.

EXPERIMENTAL RESULTS

The mixing time for each combination is given in Tables 3 to 9 and the observed mean loaf volume for each combination in Tables 10 to 16. The 1920 loaf volumes are given in Tables 36 to 63 (appendix).

Prior to subjecting the data to an analysis of variance, the correlation of the group mean loaf volumes and their respective mean variances were determined. (Table 2). It was found that the group means and their variances were significantly correlated. The correlation between the combination mean loaf volumes, within each group, and their variances was found, in all seven groups, to be definitely nonsignificant. Table 17 gives the correlation coefficients together with the least significant correlation coefficients.

Tables 18, 19, and 20 give the results of the variance analysis according to the flour-mixer groups. Table 18 gives the results of the data obtained with the Tenmarq flour. Table 19 gives the results of the data from the Chiefkan flour, and Table 20 gives the results of the data from the Commercial Mix flour. The mean squares were tested for significance by several statistical criteria.

Inasmuch as the capacity of the Working mixer prevented employing the split-loaf technique in mixing the dough, it was not practical to obtain the data in such a manner as to be able to estimate the within day variation of that group.

In the groups studied, the effect of mixing speed variations was shown to be very highly significant, with the exception of the Chiefkan groups. The speed variations on Chiefkan flour were significant, but not nearly to the extent they were on the other flours. The influence of dry milk solids was very highly significant with all the flours; however, as the graphs and equations will show, the effect of dry

Table 3. Mixing times for Tenmarq flour-Working mixer group (in minutes).

Percent DMS*	Mixing speed (RPM)						
	50	75	100	125	150	175	200
0	4.0	3.1	2.5	2.0	1.8	1.5	1.2
2	4.0	3.1	2.5	2.0	1.8	1.5	1.2
6	5.3	4.2	3.2	2.5	2.0	1.8	1.5
12	7.0	5.2	4.0	2.8	2.1	1.9	1.6

*Dry Milk Solids

Table 4. Mixing times for Tenmarq flour-Swanson Working mixer group (in minutes).

Percent DMS*	Mixing speed (RPM)						
	50	75	100	125	150	175	200
0	4.2	3.4	2.8	2.2	1.9	1.5	1.2
2	4.8	3.8	3.0	2.4	2.0	1.6	1.2
3	5.8	4.5	3.5	2.8	2.1	1.8	1.4
12	7.5	5.6	4.2	3.2	2.4	1.9	1.4

*Dry Milk Solids

Table 5. Mixing times for Tenmarq flour-Hobart McDuffee mixer group (in minutes).

Percent DMS*	Mixing speed (RPM)			
	40	70	100	130
0	10.0	4.0	2.0	1.0
2	13.0	5.5	2.5	1.0
6	22.0	8.0	3.2	1.2
12	40.0	10.5	4.7	1.5

*Dry Milk Solids

Table 6. Mixing times for Chiefkan flour-Swanson Working mixer group (in minutes).

Percent DMS*	Mixing speed (RPM)						
	50	75	100	125	150	175	200
0	1.2	1.0	0.8	0.6	0.5	0.4	0.2
2	1.5	1.1	0.9	0.8	0.5	0.4	0.2
6	2.0	1.3	1.1	0.9	0.6	0.5	0.4
12	2.8	2.0	1.5	1.0	0.8	0.5	0.4

*Dry Milk Solids

Table 7. Mixing times for Chiefkan flour-Hobart McDuffee mixer group (in minutes).

Percent DMS*	Mixing speed (RPM)			
	40	70	100	130
0	2.2	1.5	1.0	0.6
2	3.1	1.9	1.1	0.6
6	4.8	2.5	1.2	0.8
12	6.0	3.5	1.5	0.8

*Dry Milk Solids

Table 8. Mixing times for Commercial Mix flour-Swanson Working mixer group (in minutes).

Percent DMS*	Mixing speed (RPM)						
	50	75	100	125	150	175	200
0	3.4	3.0	2.5	2.4	2.1	1.9	1.6
2	4.1	3.5	3.0	2.6	2.2	1.9	1.6
6	5.6	4.5	3.3	3.0	2.5	2.0	1.8
12	8.0	5.8	4.8	3.6	3.3	2.1	1.8

*Dry Milk Solids

Table 9. Mixing times for Commercial Mix flour-Hobart McDuffee mixer group (in minutes).

Percent DMS*	Mixing speed (RPM)			
	40	70	100	130
0	4.6	3.0	2.0	1.2
2	6.8	3.9	2.2	1.4
6	10.8	5.2	2.3	1.5
12	17.0	7.5	3.5	1.6

*Dry Milk Solids

Table 10. Combination mean loaf volumes of Tenmarq flour-Working mixer group (cubic centimeters).

Percent DMS*	Mixing speed (RPM) 50	75	100	125	150	175	200
0	770	772	797	826	803	810	741
2	798	800	828	837	843	837	778
6	780	806	852	822	818	810	761
12	786	798	819	778	768	773	718

*Dry Milk Solids

Table 11. Combination mean loaf volumes of Tenmarq flour-Swanson Working mixer group (cubic centimeters).

Percent DMS*	Mixing speed (RPM) 50	75	100	125	150	175	200
0	691	744	743	757	733	756	716
2	695	742	778	770	786	771	785
6	725	773	811	796	802	790	712
12	730	792	791	792	776	749	747

*Dry Milk Solids

Table 12. Combination mean loaf volumes of Tenmarq flour-Hobart McDuffee mixer group (cubic centimeters).

Percent DMS*	Mixing speed (RPM) 40	75	100	150
0	751	782	768	724
2	784	790	781	750
6	779	798	798	731
12	773	773	791	742

*Dry Milk Solids

Table 13. Combination mean loaf volumes of Chiefkan flour-Swanson Working mixer group (cubic centimeters).

Percent DMS*	Mixing speed (RPM)						
	50	75	100	125	150	175	200
0	708	706	696	693	695	696	690
2	685	697	697	693	686	691	684
6	686	681	678	685	678	677	677
12	650	646	642	658	667	650	658

*Dry Milk Solids

Table 14. Combination mean loaf volumes of Chiefkan flour-Hobart McDuffee mixer group (cubic centimeters).

Percent DMS*	Mixing speed (RPM)			
	40	70	100	130
0	696	701	711	700
2	698	700	688	688
6	692	695	690	682
12	698	652	676	677

*Dry Milk Solids

Table 15. Combination mean loaf volumes of Commercial Mix flour-Swanson Working mixer group (cubic centimeters).

Percent DMS*	Mixing speed (RPM) 50	75	100	125	150	175	200
0	753	769	803	785	792	779	762
2	772	808	817	790	769	780	791
6	807	838	829	834	821	811	821
12	798	813	798	795	806	823	804

*Dry Milk Solids

Table 16. Combination mean loaf volumes of Commercial Mix flour-Hobart McDuffee mixer group (cubic centimeters).

Percent DMS*	Mixing speed (RPM) 40	70	100	130
0	668	683	710	702
2	704	710	721	702
6	741	763	753	723
12	770	784	775	726

*Dry Milk Solids

Table 17. The correlation of the data means with their variances.

Source of means and variances	Correlation coefficient	Least significant correlation
Group means and variances	+0.802	0.754
Combination means and variances:		
Tenmarq flour-		
Working mixer group	+0.000	0.374
Swanson Working mixer group	-0.160	0.374
Hobart McDuffee " "	-0.380	0.497
Chiefkan flour-		
Swanson Working mixer group .	+0.029	0.374
Hobart McDuffee " "	-0.442	0.497
Commercial Mix flour-		
Swanson Working mixer group .	+0.070	0.374
Hobart McDuffee " "	-0.185	0.497

Table 13. Results of the variance analyses on Tenmarq flour.

Source of variation	Working mixer df#	Working mixer Mean square	Swanson-Working mixer df#	Swanson-Working mixer Mean square	Hobart-McDuffee mixer df#	Hobart-McDuffee mixer Mean square
Mixing speed	6	31,620***	6	57,939***	3	23,851***
Dry Milk Solids	3	38,382***	3	16,443***	3	5,439***
Day-to-day	11	73,843***	5	12,037***	5	59,452***
Within-day	--	---------	168	206ns	96	106ns
Interactions:						
DMS:Speed	18	2,914**	18	5,222**	9	1,213ns
DMS:Day-to-day	13	7,024***	15	1,038ns	15	2,302*
Speed:Day-to-day	30	2,534**	30	1,275*	15	1,713ns
Unaccounted for error	252	357	90	837	45	1,441

# -degrees of freedom
ns -nonsignificant
* -significant (19 to 1)
** -highly significant (99 to 1)
*** -very highly significant (999 to 1)

Table 19. Results of the variance analyses on Chiefkan flour.

Source of variation	Swanson-Working mixer		Hobart-McDuffee mixer	
	dfƒ	Mean square	dfƒ	Mean square
Mixing speed	6	231*	3	493**
Dry milk solids	3	32,936***	3	13,812***
Day-to-day error	5	11,378***	5	2,131***
Within-day "	168	131*	36	97ns
Interactions:				
DMS x Speed	18	439**	9	1,247**
DMS x Day-to-day	15	549**	15	351ns
Speed x Day-to-day	30	206**	15	451ns
Unaccounted error	90	57	45	296

ƒ -degrees of freedom
ns -nonsignificant
* -significant (19 to 1)
** -highly significant (99 to 1)
***-very highly significant (999 to 1)

Table 20. Results of the variance analyses on Commercial Mix flour.

Source of variation	Swanson-Working mixer		Hobart-McDuffee mixer	
	df#	Mean square	df#	Mean square
Mixing speed	6	4,107***	3	7,207***
Dry milk solids	3	31,480***	3	52,837***
Day-to-day error	5	57,310***	5	706**
Within-day "	168	554ns	96	35ns
Interactions:				
DMS x Speed	18	1,620ns	9	1,242**
DMS x Day-to-day	15	976ns	15	404ns
Speed x Day-to-day	30	5,638**	15	486ns
Unaccounted error	90	981	45	412

# -degrees of freedom
ns -nonsignificant
* -significant (19 to 1)
** -highly significant (99 to 1)
***-very highly significant (999 to 1)

milk solids on Chiefkan flour was negative. With the other flours, dry milk solids had a very definite, beneficial effect.

The day-to-day variation was very definitely a factor that had to be taken into account, as was shown in the variance analysis. This factor included the effects of various uncontrollable elements among which were yeast variation from shipment to shipment and operator variability. Numerous other minor elements included in the day-to-day variation were the fluctuations of temperature and humidity in the laboratory, the fermentation and proofing cabinets, and in the oven; although these elements were controlled as rigidly as was possible with air-conditioning, thermostatic, and humidistatic apparatus.

The within-day variation was another factor which had no actual bearing on the investigation but had to be taken into account to present a more reliable picture of the phenomena studied. Within-day variation was found to be definitely nonsignificant in all cases except the first group studied. The tests on the within-day variation of the first group barely showed significance; thus, in view of the nonsignificance of all the other groups, it was assumed that no real effect was present in the first group. The within-day variation included all of the elements that were included in the day-to-day variation, but those variations measured were those occurring on a single day. The day-to-day variation considered the changes from one day to the next.

The dry milk solids-mixing speed interaction was highly significant in all groups but two. These two were the Tenmarq flour-Hobart McDuffee and the Commercial Mix-Swanson Working groups.

The dry milk solids-mixing speed interaction showed that the presence of dry milk solids markedly altered the effect of mixing speed on bread. This phenomenon will be further described when the equations are discussed. The fact that there was no significant effect of the interaction of dry milk solids and mixing speed in two of the groups would merely indicate the possibility that if a flour were mixed in the correct type of mixer the effect of mixing speed would not be altered by the dry milk solids content. However, mixing a flour in such a mixer would not, necessarily, produce the best bread. This point will be discussed later.

The other interactions were of no interest other than to remove their effect from the portion of the data that were to be studied. It was recognized as quite possible that an interaction between either, or both, dry milk solids and mixing speed with yeast might be significant. However, such a study would have had no bearing on this investigation and was disregarded.

Table 21 lists the standard errors for each of the flour-mixer groups of data. The mean loaf volumes of the flour-mixer groups (Table 2) have been repeated (Table 21). It was found that the standard errors were very highly correlated

Table 21. Standard errors of the various flour-mixer groups.

Flour-mixer group	Standard error (cubic centimeters)	Group mean loaf volumes (repeated from Table 2)
Tenmarq-Working	16.69	794
" -Swanson Working	14.76	754
" -Hobart McDuffee	16.68	769
Chiefkan-Swanson Working	7.83	680
" -Hobart McDuffee	7.14	687
Commercial Mix-Swanson Working	13.34	800
Commercial Mix-Hobart McDuffee	11.27	727

Correlation between standard error and mean loaf volumes equaled +.949, with 5 degrees of freedom.

with the mean loaf volumes; i.e., the standard errors increased with increases in the mean loaf volumes.

It was noted that the loaf volume variations due to characteristics inherent in the flour-mixer interaction were highly significant, whereas the loaf volume variations due to the characteristics imparted in the bread because of mixing speed or dry milk solids were not even remotely correlated. It thus appeared that a definite type of mixer should be used with a particular flour (as alluded to previously). The particular mixer may be one that does not give a negative regression of dry milk solids with mixing speed; or (if the optimum of the regression produces better bread) one that does produce a negative relationship. It did seem more likely, however, that the amount of dry milk solids that could best be utilized depended somewhat on the mixing speed. To illustrate, it appeared that Tenmarq flour should be mixed with a mixing action similar to that of the Working mixer (Table 2), but the Commercial wheat-blend flour should be mixed with a mixing action similar to that of the Swanson-Working mixer. However, the optimum dry milk solids content for either of these flours seemed to be dependent upon the mixing speed.

This hypothesis was further borne out by the mathematical determination of the optimum dry milk solids contents at the various speeds of mixing employed in this investigation. The mathematical determination will be discussed later.

Mathematical equations describing the influence of mixing speed and dry milk solids content on bread were developed. It was found that the relationship of mixing speed to optimum mixing time was exponential. This relationship required the general equation: $Y = KC^{BX}$, where Y = mixing time in minutes, C and K = constants, and X = revolutions per minute. The transformed equation became: $\text{Log } Y = K_1 + BX$, where Y = mixing time in minutes, K_1 and B = constants, and X = revolutions per minute. This type of equation accounted for 98 percent of the variations in mixing times. Table 22 presents the specific equations for each of the 28 flour-mixer-milk subgroups.

The relationship between optimum mixing time and dry milk solids content was linear and required the following general equation: $Y = K + BX$, where Y = mixing time in minutes, K and B = constants, X = percentage dry milk solids. This linear relationship accounted for 99 percent of the variations in mixing times. Table 23 presents the specific equations for each of the 40 flour-mixer-speed subgroups.

An attempt was made to develop a multiple-regression equation by which the mixing time could be estimated with simultaneous regard to both mixing speed and dry milk solids content. The equations that could be obtained, with the available data, accounted for only 83 percent of the variation in mixing times. As it was found that an estimated mixing time of four minutes might well have an error of half a minute, it was decided to dispense with the exact equations. The general equation was as follows: $\text{Log } Y = A + \log(X + 1) + BZ$, where Y = mixing time in minutes, A and B = constants, X = percentage dry milk solids, and Z = revolutions per minute.

The loaf volume relationships to both mixing time and dry milk solids content were found to be quadratic; i. e., $Y = A + BX + CX^2$, where Y = loaf volume in cubic centimeters, A, B, and C = constants, X = revolutions per minute or dry milk solids percent. With this type of equation, mixing speed accounted for more than 97 percent of the variation in loaf volume; and dry milk solids accounted for more than 95 percent of the variation in loaf volume. Tables 24 and 25 present the specific equations for the loaf volume relationships.

Inasmuch as the specific equations accounted for 98 percent of the variations in mixing times and 95 percent of the variations in loaf volume, the graphs of the various relationships were drawn according to the calculated data.

The standard errors of estimate for both the mixing time-RPM and the mixing time-dry milk solids relationships were calculated to be .130 and .128 minutes respectively. The standard errors of estimate for the loaf volume-RPM and the loaf volume-dry milk solids relationships were calculated to be 9.00 and 13.26 cc, respectively.

The first derivative of each of the loaf volume equations was taken. The derivative of each of the loaf volume equations

Table 22. Regression equations of mixing speed versus mixing time (speed in RPM, time in minutes).

Flour-mixer group	Percent DMS	Equations: Y = mixing time; X = RPM
Tenmarq-Working	0	Log10Y* = 1.74838 - .003298X
	2	" = 1.74238 - .003238X
	6	" = 1.91904 - .003903X
	12	" = 2.03680 - .004388X
Tenmarq-Swanson Working	0	Log10Y* = 1.79652 - .003522X
	2	" = 1.85922 - .003774X
	6	" = 1.96161 - .004144X
	12	" = 2.11756 - .004262X
Tenmarq-Hobart McDuffee	0	Log10Y* = 2.41105 - .011000X
	2	" = 2.60692 - .0[illegible]1X
	6	" = 2.86307 - .013759X
	12	" = 3.17869 - .015408X
Chiefkan-Swanson Working	0	Log10Y* = 1.33666 - .004482X
	2	" = 1.47000 - .005176X
	6	" = 1.53963 - .004844X
	12	" = 1.74151 - .005859X
Chiefkan-Hobart McDuffee	0	Log10Y* = 1.60279 - .006150X
	2	" = 1.81071 - .007729X
	6	" = 2.02535 - .009020X
	12	" = 2.35266 - .011501X
Commercial Mix-Swanson-Working	0	Log10Y* = 1.62235 - .002074X
	2	" = 1.74097 - .002667X
	6	" = 1.92675 - .003569X
	12	" = 2.12066 - .004513X
Commercial Mix-Hobart McDuffee	0	Log10Y* = 1.91793 - .006269X
	2	" = 2.13128 - .007697X
	6	" = 2.39601 - .009456X
	12	" = 2.67555 - .011299X

*The logarithms of ten times the actual mixing time was used so that negative logarithms, when the mixing time was less than one minute, could be avoided.

Table 23. Regression equations of percent dry milk solids versus mixing time (time in minutes).

Flour-mixer group	Mixing speed (RPM)	Equations: Y = mixing time; X = % DM
Tenmarq-Working	50	Y = 3.8335 + 0.2708X
	75	Y = 2.8651 + 0.1905X
	100	Y = 2.3929 + 0.1339X
	125	Y = 1.9703 + 0.0654X
	150	Y = 1.7361 + 0.0342X
	175	Y = 1.4861 + 0.0342X
	200	Y = 1.2361 + 0.0342X
Tenmarq-Swanson Working	50	Y = 4.2080 + 0.2709X
	75	Y = 3.3750 + 0.1775X
	100	Y = 2.7500 + 0.1250X
	125	Y = 2.2322 + 0.0649X
	150	Y = 1.2626 + 0.0402X
	175	Y = 1.5386 + 0.0298X
	200	Y = 1.2530 + 0.0119X
Tenmarq-Hobart McDuffee	40	Y = 8.5715 + 2.5357
	70	Y = 4.3215 + 0.5357X
	100	Y = 1.9940 + 0.2262X
	130	Y = 0.9045 + 0.0666X
Chiefkan-Swanson Working	50	Y = 1.2500 + 0.1250X
	75	Y = 0.9823 + 0.0648X
	100	Y = 0.7550 + 0.0615X
	125	Y = 0.6562 + 0.0312X
	150	Y = 0.4323 + 0.0223X
	175	Y = 0.3790 + 0.0119X
	200	Y = 0.2530 + 0.0119
Chiefkan-Hobart McDuffee	40	Y = 2.1428 + 0.4777
	70	Y = 1.5178 + 0.1632X
	100	Y = 1.0178 + 0.0402X
	130	Y = 0.8280 + 0.0119
Commercial Mix-Swanson Working	50	Y = 3.3542 + 0.3654X
	75	Y = 2.9820 + 0.2411X
	100	Y = 2.6458 + 0.1771X
	125	Y = 2.3928 + 0.1027X
	150	Y = 2.1260 + 0.0625
	175	Y = 1.8572 + 0.0283
	200	Y = 1.6250 + - - - -
Commercial Mix-Hobart McDuffee	40	Y = 4.6398 + 1.0283X
	70	Y = 3.0638 + 0.3705
	100	Y = 2.0000 + 0.1250X
	130	Y = 1.2985 + 0.0298X

Table 24. Regression equations of loaf volume versus mixing speed (volume in cubic centimeters, speed in RPM).

Flour-mixer group	Percent [illegible]	Equations: Y = loaf volume, X = RPM
Tenmarq-Working	0	$Y = 645.3 + 2.756X - .01104X^2$
	2	$Y = 693.3 + 2.280X - .00896X^2$
	6	$Y = 676.7 + 2.644X - .01104X^2$
	12	$Y = 689.8 + 2.008X - .00928X^2$
Tenmarq-Swanson Working	0	$Y = 587.7 + 2.648X - .00992X^2$
	2	$Y = 552.4 + 3.504X - .01312X^2$
	6	$Y = 564.9 + 3.984X - .01600X^2$
	12	$Y = 659.5 + 2.168X - .00896X^2$
Tenmarq-Hobart McDuffee	0	$Y = 674.8 + 2.676X - .01778X^2$
	2	$Y = 737.3 + 1.315X - .01111X^2$
	6	$Y = 702.1 + 2.731X - .0188$[illegible]$X^2$
	12	$Y = 712.8 + 1.926X - .01277X^2$
Chiefkan-Swanson Working	0	$Y = 714.2 - 0.176X - .0003$[illegible]$X^2$
	2	$Y = 674.3 + 0.360X - .0016$[illegible]$X^2$
	6	$Y = 688.2 + 0.132X - .00112X^2$
	12	$Y = 625.0 + 0.320X - .00096X^2$
Chiefkan-Hobart McDuffee	0	$Y = 672.0 + 0.724X - .00388X^2$
	2	$Y = 701.9 - 0.057X - .00055X^2$
	6	$Y = 682.5 + 0.359X - .00267X^2$
	12	$Y = 621.8 + 0.650X - .00167X^2$
Commercial Mix-Swanson Working	0	$Y = 684.5 + 1.680X - .00656X^2$
	2	$Y = 755.4 + 0.760X - .00320X^2$
	6	$Y = 786.5 + 0.732X - .00304X^2$
	12	$Y = 803.1 - 0.052X + .00048X^2$
Commercial Mix-Hobart McDuffee	0	$Y = 616.7 + 1.362X - .00611X^2$
	2	$Y = 660.6 + 1.336X - .00777X^2$
	6	$Y = 675.1 + 2.242X - .0144$[illegible]$X^2$
	12	$Y = 701.8 + 2.366X - .01567X^2$

Table 25. Regression equations of loaf volume versus percent dry milk solids (volume in cubic centimeters).

Flour-mixer group	Mixing speed: (RPM)	Equations: Y = loaf volume, X = %DMS
Tenmarq-Working	50	$Y = 782 + 5.20X - 0.59X^2$
	75	$Y = 735 + 9.50X - 0.63X^2$
	100	$Y = 817 + 16.50X - 1.22X^2$
	125	$Y = 826 + 21.67X - 2.12X^2$
	150	$Y = 824 + 7.76X - 1.02X^2$
	175	$Y = 822 + 4.18X - 0.67X^2$
	200	$Y = 758 + 9.78X - 1.01X^2$
Tenmarq-Swanson Working	50	$Y = 695 + 7.72X - 0.34X^2$
	75	$Y = 745 + 5.23X - 0.07X^2$
	100	$Y = 764 + 18.22X - 1.20X^2$
	125	$Y = 766 + 9.02X - 0.59X^2$
	150	$Y = 776 + 12.04X - 0.92X^2$
	175	$Y = 768 + 12.07X - 1.04X^2$
	200	$Y = 718 - 3.42X + 0.46X^2$
Tenmarq-Hobart McDuffee	40	$Y = 766 + 8.13X - 0.59X^2$
	70	$Y = 785 + 6.02X - 0.56X^2$
	100	$Y = 770 + 10.74X - 0.88X^2$
	130	$Y = 734 + 1.66X - 0.08X^2$
Chiefkan-Swanson Working	50	$Y = 697 - 2.60X - 0.12X^2$
	75	$Y = 702 - 3.59X - 0.13X^2$
	100	$Y = 696 - 1.33X - 0.28X^2$
	125	$Y = 697 - 1.34X - 0.16X^2$
	150	$Y = 700 - 3.46X - 0.10X^2$
	175	$Y = 694 - 2.17X - 0.14X^2$
	200	$Y = 687 - 1.01X - 0.11X^2$
Chiefkan-Hobart McDuffee	40	$Y = 698 + 2.63X - 0.55X^2$
	70	$Y = 700 + 4.84X - 0.71X^2$
	100	$Y = 701 - 4.60X + 0.16X^2$
	130	$Y = 694 - 4.24X + 0.21X^2$
Commercial Mix-Swanson Working	50	$Y = 761 + 27.62X - 1.94X^2$
	75	$Y = 790 + 19.52X - 1.34X^2$
	100	$Y = 812 + 9.05X - 0.79X^2$
	125	$Y = 792 + 14.78X - 1.10X^2$
	150	$Y = 792 + 8.70X - 0.56X^2$
	175	$Y = 782 + 6.60X - 0.21X^2$
	200	$Y = 778 + 16.20X - 1.06X^2$
Commercial Mix-Hobart McDuffee	40	$Y = 686 + 16.06X - 0.65X^2$
	70	$Y = 699 + 12.04X - 0.78X^2$
	100	$Y = 717 + 8.72X - 0.26X^2$
	130	$Y = 704 + 4.69X - 0.20X^2$

was then tested for a maximum or minimum (there could be only one maximum or minimum inasmuch as the equation was of the second degree). All but four equations from both the RPM and the dry milk solids relationships had a maximum point; i.e. an optimum mixing speed and an optimum dry milk solids content.

From the determination of optimum mixing speeds at various dry milk solids levels, it was noted that in four of the groups the optimum speed decreased as the dry milk solids content increased. However, the differences in optimum mixing speed at the four dry milk solids levels were insufficient to obtain significant regression and to allow reliable mathematical expression because of the variation within each level. Negative correlation between percentage dry milk solids and optimum mixing speed approached significance when all the available data were considered. Portions of the data (Tenmarq-Working group, etc.) were very definitely correlated, but the overall picture was marred by the abnormal characteristics of Chiefkan flour. This same observation of negative dry milk solids-mixing speed regression was not quite so obvious from the determination of the optimum dry milk solids content at various speeds, although the trend was discernible.

The derivatives of the loaf volume-dry milk solids equations definitely showed that both Tenmarq flour and the Commercial Mix flour produced superior bread with the addition of dry milk solids, whereas Chiefkan produced progressively poorer loaves with increases in dry milk solids content.

Tables 26 and 27 present the first derivatives and the optimum speeds and dry milk solids contents which were discussed above.

The second derivatives of the loaf volume-dry milk solids equations were taken. A correlation between the second derivatives and their respective dry milk solids content was made. An overall, nonsignificant correlation of +.0077 was obtained, with 26 degrees of freedom. Correlations were also made between portions of the second derivatives; they were between zero and two percent dry milk solids, zero and six percent dry milk solids, and zero and 12 percent dry milk solids. These correlations did not approach significance, either. Therefore, there seems to be no improvement in the mixing speed tolerance when dry milk solids has been added, as measured by loaf volume. This does not agree with the findings of Stamberg and Bailey (1938).

Multiple-regression equations of loaf volume against mixing speed and dry milk solids content were developed. However, the inclusion of both mixing speed and dry milk solids content into a simultaneous consideration of their effect on loaf volume accounted for only 85 percent of the variation. Therefore, the practical value of this type of equation for estimation of loaf volumes was no better than the multiple-regression equation for mixing time. However, enough of the variation was removed to show that the relationship was curvilinear and had the following general

Table 26. First derivative and optimum RPM of loaf volume-mixing speed relationship.

Flour-mixer group	Percent [illegible]	First derivative	Optimum RPM
Tenmarq-Working	0	Y' = 2.756 - .02208X	125
	2	Y' = 2.288 - .01792X	128
	6	Y' = 2.644 - .02208X	120
	12	Y' = 2.008 - .01856X	108
Tenmarq-Swanson Working	0	Y' = 2.648 - .01984X	134
	2	Y' = 3.504 - .02624X	134
	6	Y' = 3.984 - .03200X	124
	12	Y' = 2.168 - .01792X	121
Tenmarq-Hobart McDuffee	0	Y' = 2.676 - .03556X	75
	2	Y' = 1.515 - .02222	68
	6	Y' = 2.731 - .03776X	72
	12	Y' = 1.926 - .02554X	75
Chiefkan-Swanson Working	0	Y' =-0.176 - .00064X	-272
	2	Y' = 0.360 - .00320X	112
	6	Y' = 0.132 - .00224X	59
	12	Y' = 0.320 - .00192X	167
Chiefkan-Hobart McDuffee	0	Y' = 0.724 - .00776X	93
	2	Y' =-0.057 - .00110X	-52
	6	Y' = 0.359 - .00534X	67
	12	Y' = 0.650 - .00334X	195
Commercial Mix-Swanson Working	0	Y' = 1.680 - .01312X	128
	2	Y' = 0.760 - .00640X	119
	6	Y' = 0.732 - .00608X	120
	12	Y' =-0.052 + .00096X	54*
Commercial Mix-Hobart McDuffee	0	Y' = 1.352 - .01222X	111
	2	Y' = 1.336 - .01554X	86
	6	Y' = 2.242 - .02886X	78
	12	Y' = 2.366 - .03334X	71

* A minimum value

Table 27. First derivatives and optimum dry milk solids of loaf volume-dry milk solids relationship.

Flour-mixer group	Mixing speed (RPM)	First derivative	Optimum % DMS
Tenmarq-Working	50	Y' = 5.20 - 1.18X	4.41
	75	Y' = 9.50 - 1.26X	7.54
	100	Y' =16.50 - 2.44X	6.72
	125	Y' =21.67 - 4.24X	5.11
	150	Y' = 7.76 - 2.04X	3.80
	175	Y' = 4.18 - 1.34X	3.12
	200	Y' = 9.78 - 2.02X	4.84
Tenmarq-Swanson Working	50	Y' = 7.72 - 0.68X	11.35
	75	Y' = 5.23 - 0.14X	37.36
	100	Y' =18.22 - 2.40X	7.59
	125	Y' = 9.92 - 1.16X	8.55
	150	Y' =12.04 - 1.84X	6.54
	175	Y' =12.07 - 2.08X	5.80
	200	Y' =-3.42 + 0.92X	3.72*
Tenmarq-Hobart McDuffee	40	Y' = 8.18 - 1.18X	6.93
	70	Y' = 6.02 - 1.12X	5.38
	100	Y' =10.74 - 1.36X	7.90
	130	Y' = 1.66 - 0.16X	10.38
Chiefkan-Swanson Working	50	Y' =-2.60 - 0.24X	-10.83
	75	Y' =-3.39 - 0.26X	-13.04
	100	Y' =-1.33 - 0.56X	- 2.38
	125	Y' =-1.34 - 0.32X	- 4.19
	150	Y' =-3.46 - 0.20X	-17.30
	175	Y' =-2.17 - 0.28X	- 7.75
	200	Y' =-1.01 - 0.22X	- 4.59
Chiefkan-Hobart McDuffee	40	Y' = 2.63 - 1.10X	2.37
	70	Y' = 4.84 - 1.42X	3.41
	100	Y' =-4.60 + 0.36X	12.77*
	130	Y' =-4.24 + 0.42X	10.10*
Commercial Mix-Swanson Working	50	Y' =27.62 - 3.88X	7.12
	75	Y' =19.52 - 2.68X	7.28
	100	Y' = 9.05 - 1.58X	5.73
	125	Y' =14.76 - 2.20X	6.72
	150	Y' = 8.70 - 1.12X	7.77
	175	Y' = 6.60 - 0.42X	15.71
	200	Y' =16.20 - 2.12X	7.63
Commercial Mix-Hobart McDuffee	40	Y' =16.06 - 1.30X	12.35
	70	Y' =18.04 - 1.56X	11.56
	100	Y' = 8.72 - 0.52X	16.77
	130	Y' = 4.69 - 0.40X	11.72

*A minimum value.

equation: $Y = A + BX_1 + CX_2 + DX_1^2 + EX_2^2$, where Y = loaf volume, X_1 = percent dry milk solids, X_2 = revolutions per minute, and A, B, C, D, and E = constants.

It seemed obvious that different mixers would possess different optimum mixing speeds and different flours possess different optimum dry milk solids contents, according to their various characteristics. In addition, however, the partial first derivative of the above equations also indicated differences in optimum mixing speed for different flours on the same mixer and different optimum dry milk solids contents for different mixers using the same flours. Table 28 gives the partial first derivatives of each of the above mentioned equations with respect to dry milk solids and mixing speeds, together with the optimum dry milk solids content and optimum mixing speed for each flour-mixer group.

Tables 29 and 30 give the calculated mixing time for the various combinations employed during the course of this investigation. Plates I and II present the graphs of the calculated mixing times. The calculated data were obtained by using the equations of Tables 22 and 23, respectively. Tables 31 and 32 give the calculated loaf volumes as obtained by the equations of Tables 24 and 25, respectively. Plates III and IV present the graphs of the calculated loaf volumes.

Graphical analysis of the logarithmic form of the exponential relationship of mixing time versus mixing speed indicated that the equations converge on each other as the mixing speed increases. This led to the assumption that there was

Table 23. Partial first derivatives of loaf volume multiple-regression equations with optimum dry milk solids content and mixing speed for each flour-mixer group.

Flour-mixer group	Partial first derivative	Optimum % DMS	Optimum RPM
Tenmarq-Working	Y' for DMS = 7.9165 - 1.6398X Y' " RPM = 1.9[illegible]63 - 0.0172X	4.83	116
Tenmarq-Swanson Working	Y' for DMS = 8.8263 - 1.0534X Y' " RPM = 3.0757 - 0.0240X	8.38	128
Tenmarq-Hobart McDuffee	Y' for DMS = 6.6264 - 0.9450X Y' " RPM = 2.4230 - 0.0328X	7.01	74
Chiefkan-Swanson Working	Y' for DMS =-2.2921 - 0.2282X Y' " RPM = 0.0764 - 0.0008X	-10.05	96
Chiefkan-Hobart McDuffee	Y' for DMS =-1.1369 - 0.3154X Y' " RPM = 0.4402 - 0.0046X	- 3.60	96
Commercial Mix-Swanson Working	Y' for DMS =12.6996 - 1.6856X Y' " RPM = 0.2107 - 0.0018X	7.54	117
Commercial Mix-Hobart McDuffee	Y' for DMS =11.8201 - 0.9408X Y' " RPM = 1.8408 - 0.0224X	12.58	83

Table 29. Calculated mixing times from regression equations of mixing time-RPM relationships (in minutes).

Flour-mixer group	Percent DMS	Mixing speed 50	75	100	125	150	175	200
Tenmarq-Working	0	3.8	3.1	2.6	2.1	1.8	1.5	1.2
	2	3.8	3.1	2.6	2.1	1.8	1.5	1.2
	6	5.3	4.2	3.4	2.7	2.2	1.7	1.4
	12	6.6	5.1	4.0	3.1	2.4	1.8	1.4
Tenmarq-Swanson Working	0	4.2	3.4	2.9	2.3	1.8	1.5	1.2
	2	4.7	3.8	3.0	2.4	2.0	1.6	1.3
	6	5.7	4.5	3.5	2.8	2.2	1.7	1.4
	12	7.3	5.6	4.3	3.2	2.4	1.8	1.4
Tenmarq-Hobart McDuffee	0	7.3	3.9	2.0	1.1	0.6	0.3	0.1
	2	9.9	4.9	2.4	1.2	0.6	0.3	0.1
	6	15.7	7.1	3.2	1.5	0.7	0.3	0.1
	12	25.6	10.5	4.3	1.8	0.7	0.3	0.1
Chiefkan-Swanson Working	0	1.3	1.0	0.8	0.6	0.5	0.4	0.3
	2	1.6	1.2	0.9	0.7	0.5	0.4	0.3
	6	2.0	1.5	1.1	0.8	0.6	0.5	0.4
	12	2.6	2.0	1.4	1.0	0.7	0.5	0.4
Chiefkan-Hobart McDuffee	0	2.0	1.4	1.0	0.7	0.5	0.3	0.2
	2	2.6	1.7	1.1	0.7	0.4	0.3	0.2
	6	3.3	2.2	1.3	0.8	0.5	0.3	0.2
	12	6.0	3.1	1.6	0.8	0.4	0.2	0.1
Commercial Mix-Swanson Working	0	3.4	3.0	2.7	2.4	2.1	1.8	1.6
	2	4.4	3.5	3.0	2.6	2.2	1.9	1.6
	6	5.6	4.6	3.7	3.0	2.5	2.0	1.6
	12	7.8	6.0	4.7	3.6	2.8	2.1	1.6
Commercial Mix-Hobart McDuffee	0	4.0	2.8	2.0	1.4	0.9	0.7	0.5
	2	5.6	3.6	2.2	1.5	0.9	0.5	0.4
	6	8.4	4.9	2.8	1.6	1.0	0.5	0.3
	12	12.9	6.7	3.5	1.8	1.0	0.5	0.3

EXPLANATION OF PLATE I

Calculated mixing times from the regression of mixing time versus mixing speed.

Fig. 1. Tenmarq flour; Working mixer

Fig. 2. Tenmarq flour; Swanson-Working mixer

Fig. 3. Tenmarq flour; Hobart-McDuffee mixer

Fig. 4. Chiefkanflour; Swanson-Working mixer

Fig. 5. Chiefkan flour; Hobart-McDuffee mixer

Fig. 6. Commercial Mix flour; Swanson-Working mixer

Fig. 7. Commercial Mix flour; Hobart-McDuffee mixer

PLATE I

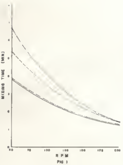


FIG 1

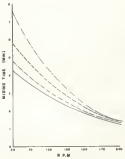


FIG 2

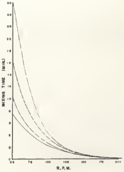


FIG 3

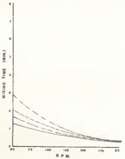


FIG 4

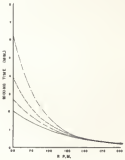


FIG 5

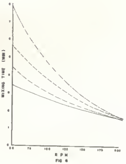


FIG 6

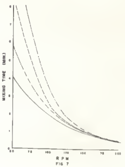


FIG 7

LEGEND
0 % DMS ———
2 % DMS — — —
6 % DMS —·—
12 % DMS — —

Table 30. Calculated mixing times from regression equations of mixing time-[illegible] relationships (in minutes).

Flour-mixer group	Mixing speed	Percent DSS 0	2	6	12
Tenmarq-Working	50	3.8	4.4	5.5	7.1
	75	3.0	3.4	4.1	5.3
	100	2.4	2.7	3.2	4.0
	125	2.0	2.1	2.4	2.8
	150	1.7	1.8	1.9	2.1
	175	1.5	1.6	1.7	1.9
	200	1.2	1.3	1.4	1.6
Tenmarq-Swanson Working	50	4.2	4.7	5.8	7.5
	75	3.4	3.8	4.5	5.6
	100	2.8	3.0	3.5	4.2
	125	2.2	2.4	2.7	3.2
	150	1.9	1.9	2.1	2.3
	175	1.5	1.6	1.7	1.9
	200	1.2	1.3	1.3	1.4
Tenmarq-Hobart McDuffee	40	8.6	13.6	23.8	39.0
	70	4.3	5.4	7.4	10.7
	100	2.0	2.4	3.4	4.7
	130	0.9	1.0	1.2	1.6
Chiefkan-Swanson Working	50	1.2	1.5	2.0	2.8
	75	1.0	1.2	1.3	2.0
	100	0.8	0.9	1.1	1.5
	125	0.7	0.7	0.8	1.0
	150	0.5	0.5	0.6	0.8
	175	0.4	0.4	0.4	0.5
	200	0.2	0.3	0.3	0.4
Chiefkan-Hobart McDuffee	40	2.1	3.1	5.0	7.9
	70	1.5	1.8	2.5	3.5
	100	1.0	1.1	1.2	1.5
	130	0.6	0.6	0.7	0.8
Commercial Mix-Swanson Working	50	3.4	4.1	5.7	8.0
	75	3.0	3.5	4.4	5.9
	100	2.6	3.0	3.7	4.8
	125	2.4	2.6	3.0	3.6
	150	2.1	2.2	2.5	2.9
	175	1.8	1.9	2.0	2.1
	200	1.6	1.6	1.6	1.6
Commercial Mix-Hobart McDuffee	40	4.6	6.7	10.8	17.0
	70	3.0	3.8	5.3	7.5
	100	2.0	2.2	2.8	3.5
	130	1.3	1.3	1.5	1.6

EXPLANATION OF PLATE II

Calculated mixing times from the regression of mixing time versus dry milk solids content.

Fig. 1. Tenmarq flour; Working mixer

Fig. 2. Tenmarq flour; Swanson-Working mixer

Fig. 3. Tenmarq flour; Hobart-McDuffee mixer

Fig. 4. Chiefkan flour; Swanson-Working mixer

Fig. 5. Chiefkan flour; Hobart-McDuffee mixer

Fig. 6. Commercial Mix flour; Swanson-Working mixer

Fig. 7. Commercial Mix flour; Hobart-McDuffee mixer

PLATE II

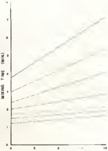


FIG 1

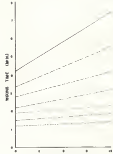


FIG 2

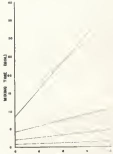


FIG 3

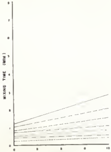


FIG 4

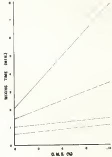


FIG 5

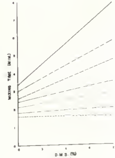


FIG 6

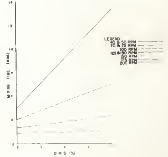


FIG 7

Table 31. Calculated loaf volumes from regression equations of loaf volume-RPM relationships (in cubic centimeters).

Flour-mixer group	Percent DMS	Mixing speed 50	75	100	125	150	175	200
Tenmarq-Working	0	756	790	810	817	810	790	753
	2	785	815	832	839	835	819	786
	6	781	813	831	835	825	801	764
	12	767	788	798	797	782	757	720
Tenmarq-Swanson Working	0	695	730	753	763	761	748	719
	2	695	741	772	785	783	764	738
	6	724	774	805	813	802	772	722
	12	746	772	787	790	783	764	736
Tenmarq-Hobart McDuffee	0	764	778	785	732	678	609	499
	2	735	759	778	754	715	665	597
	6	791	801	786	748	687	602	493
	12	771	785	778	754	714	659	587
Chiefkan-Swanson Working	0	706	703	700	697	695	693	692
	2	698	692	694	694	692	688	682
	6	692	692	690	687	683	677	670
	12	639	644	647	650	651	652	651
Chiefkan-Hobart McDuffee	0	698	704	706	702	695	680	662
	2	698	694	691	686	681	675	668
	6	694	694	692	686	679	664	646
	12	651	661	670	677	682	684	685
Commercial Mix-Swanson Working	0	752	774	787	792	789	778	758
	2	765	794	799	800	737	790	779
	6	816	824	829	831	825	822	811
	12	802	802	803	804	806	809	812
Commercial Mix-Hobart McDuffee	0	670	684	692	692	684	668	645
	2	708	717	716	707	686	656	617
	6	751	763	755	730	686	625	546
	12	778	786	772	737	682	605	508

EXPLANATION OF PLATE III

Calculated loaf volumes from the regression of loaf volume versus mixing speed.

Fig. 1. Tenmarq flour; Working mixer

Fig. 2. Tenmarq flour; Swanson-Working mixer

Fig. 3. Tenmarq flour; Hobart-McDuffee mixer

Fig. 4. Chiefkan flour; Swanson-Working mixer

Fig. 5. Chiefkan flour; Hobart-McDuffee mixer

Fig. 6. Commercial Mix flour; Swanson-Working mixer

Fig. 7. Commercial Mix flour; Hobart-McDuffee mixer

PLATE III

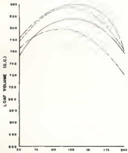


FIG 1

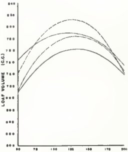


FIG 2

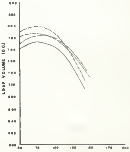


FIG 3

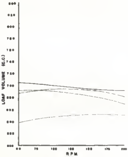


FIG 4

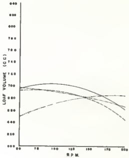


FIG 5

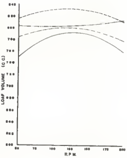


FIG 6

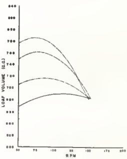


FIG 7

LEGEND
0% DMS ———
2% DMS — — —
6% DMS — — —
12% DMS — — -

Table 32. Calculated loaf volumes from regression equations of loaf volume-[illegible] relationships (in cubic centimeters).

Flour-mixer group	Mixing speed	Percent DMS 0	2	6	9	12
Tenmarq-Working	50	792	790	792	781	759
	75	785	801	819	819	808
	100	817	845	872	867	839
	125	826	861	880	849	781
	150	824	831	834	811	770
	175	822	828	823	805	776
	200	753	774	780	764	730
Tenmarq-Swanson Working	50	695	709	728	737	739
	75	745	755	773	786	798
	100	764	796	830	831	810
	125	768	784	805	808	801
	150	776	796	815	810	798
	175	766	786	800	790	761
	200	718	713	714	724	745
Tenmarq-Hobart McDuffee	40	768	780	794	792	779
	70	785	795	801	794	777
	100	770	789	810	812	725
	130	734	737	741	743	748
Chiefkan-Swanson Working	50	687	691	677	664	649
	75	702	695	677	661	643
	100	696	692	678	661	641
	125	697	694	683	672	658
	150	700	693	676	661	644
	175	694	689	676	663	648
	200	687	685	677	669	659
Chiefkan-Hobart McDuffee	40	698	701	694	677	650
	70	700	707	703	686	656
	100	701	693	660	674	672
	130	694	685	676	673	673
Commercial Mix-Swanson Working	50	761	806	857	852	813
	75	790	824	859	857	831
	100	812	827	838	839	807
	125	792	817	841	836	811
	150	792	807	824	825	816
	175	782	794	814	825	831
	200	778	806	837	832	820
Commercial Mix-Hobart McDuffee	40	686	716	759	778	765
	70	699	732	761	728	803
	100	717	733	760	774	784
	130	704	713	725	730	732

EXPLANATION OF PLATE IV

Calculated loaf volumes from the regression of loaf volume versus dry milk solids content.

Fig. 1. Tenmarq flour; Working mixer

Fig. 2. Tenmarq flour; Swanson-Working mixer

Fig. 3. Tenmarq flour; Hobart-McDuffee mixer

Fig. 4. Chiefkan flour; Swanson-Working mixer

Fig. 5. Chiefkan flour; Hobart-McDuffee mixer

Fig. 6. Commercial Mix flour; Swanson-Working mixer

Fig. 7. Commercial Mix flour; Hobart-McDuffee mixer

PLATE IV

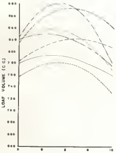


FIG 1

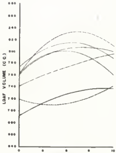


FIG 2

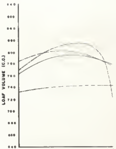


FIG 3

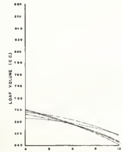


FIG 4

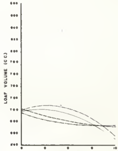


FIG 5

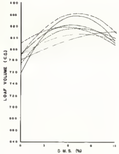


FIG 6

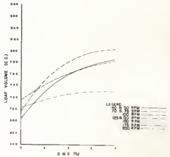


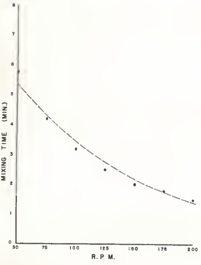
FIG 7

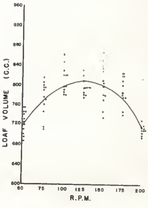
EXPLANATION OF PLATE V

Illustrations of the distribution of observed data.

The curves were obtained by mathematical development of the observed data.

PLATE V


MIXING TIME (MIN.)
0
1
2
3
4
5
6
7
8
50
75
100
125
150
175
200
R. P. M.


LOAF VOLUME (C.C.)
600
640
680
720
760
800
840
880
920
960
50
75
100
125
150
175
200
R.P.M.

a common point beyond which there was no appreciable change in optimum mixing time regardless of the mixing speed or dry milk solids content. If there were such a common point, the slope of the curve would decrease (become less negative) with an increase in the value of the Y-intercept of the curve. The Y-intercept was a function of the dry milk solids content and increased with increased amounts of dry milk solids. It was found that the correlation was -.854 (.478 would have been highly significant). This degree of correlation accounted for about 75 percent of the total variation between slope and intercept. This correlation analysis assumed a universal common point and did not allow for the possibility that there may well have been a distinct common point for each flour-mixer group. The correlation coefficients for each flour-mixer group were determined. They are listed in Table 33. The correlation between slope and intercept within each flour-mixer group was perfect in several cases and highly significant in all cases. It was thus indicated that the common point is characteristic of the flour-mixer group. By means of the calculus, it was possible to develop equations that would determine the common point in general, or for each flour-mixer group. The equations were: $A = Sxy/Sy^2$ and $B = \frac{(SY^2)(SX) - (SY)(SXY)}{nSy^2}$, where A = minimum mixing speed, B = maximum mixing time, X = Y - intercept, Y = slope, x = deviations of Y - intercept, y = deviations of slope.

Graphical analysis, also, of the mixing time-dry milk solids content relationships indicated that the rate of change

Table 33. Intercept-slope correlation coefficients within flour-mixer groups.

Flour-mixer group	Intercept-slope correlation coefficients	Degrees of freedom
Tenmarq-Working	-1.000	2
Tenmarq-Swanson Working	-1.000	2
Tenmarq-Hobart McDuffee	-0.996	2
Chiefkan-Swanson Working	-0.774	2
Chiefkan-Hobart McDuffee	-0.931	2
Commercial Mix-Swanson Working	-1.000	2
Commercial Mix-Hobart McDuffee	-0.995	2
Between group correlation	-0.834	26

of mixing time decreased with increased mixing speed regardless of the dry milk solids content. Therefore, when the speed of mixing becomes sufficiently high the rate of change of mixing time should approach zero for any dry milk solids content. The minimum mixing speed at which there would be no appreciable change in mixing time should be the same as that of the common point mixing speed of the above discussion; and the common point mixing time should be the same as that of the mixing time when the rate of change of mixing time becomes zero.

Equations, therefore, were developed which would estimate the mixing speed at which the rate of change of mixing time approached zero. The mixing speeds thus obtained were the same as the common point mixing speeds, within experimental error, as were the estimated mixing times at these points. The mixing times were estimated by using the equations given in Table 22. The equations used to obtain the mixing speed at zero slope are given in Table 34.

The correlation between the two methods of estimating the mixing speed beyond which there would be no measurable change in mixing time was found to be highly significant, as was the correlation between the two methods of estimating the mixing time appropriate to the mixing speed. The correlation coefficients were +.913 and +.853, respectively, with five degrees of freedom for each.

The values of these mixing speeds and mixing times, as found by both the common point and the zero slope techniques, are given in Table 35.

Table 34. Regression equations of slope-RPM relationship.

Flour-mixer group	Regression equations X = slope of DMS-mixing time curve* Y = reciprocal of mixing speed
Tenmarq-Working	Y = .003665 + .0562X
Tenmarq-Swanson Working	Y = .003660 + .0556X
Tenmarq-Hobart McDuffee	Y = .008744 + .0066X
Chiefkan-Swanson Working	Y = .005703 + .1228X
Chiefkan-Hobart McDuffee	Y = .0080121+ .0389X
Commercial Mix-Swanson Working	Y = .004374 + .0334X
Commercial Mix-Hobart McDuffee	Y = .0076306+ .0170X

*The slope of the DMS-mixing time curves are obtained by taking the first derivative of the equations presented in Table 23.

Table 36. Minimum mixing speeds and maximum mixing times as determined by common point and zero slope techniques.

Flour-mixer group	Minimum mixing speed (revolutions per min.)		Maximum mixing time (in minutes)	
	Common point	Zero slope	Common point	Zero slope
Tenmarq-Working	273	273	.91	.70
" - Swanson Working	237	269	.97	.75
" -Hobart McDuffee	176	164	.47	.41
Chiefkan-Swanson Working	223	297	.38	.11
" -Hobart McDuffee	141	123	.73	.75
Commercial Mix-Swanson-Working	201	229	1.21	1.33
Commercial Mix-Hobart McDuffee	131	131	.97	1.40
Correlation between the two techniques	+.913(5df)		+.883(5df)	

DISCUSSION

The mathematics employed to interpret the data were the techniques of statistics, analytical geometry, and the calculus. The techniques of statistics used were the variance analysis, correlation analysis, and the computation of standard errors. Analytical geometry was used to develop the equations presented in the thesis. The calculus was employed to determine the optimum mixing speeds and optimum dry milk solids contents.

Although the primary object of this study was to observe the effect of changes in mixing speeds and changes in dry milk solids content on bread, a very important secondary object was the development of mathematical tools to evaluate the changes brought about by the various mixing speeds and dry milk solids contents. In the pursuit of scientific truths, it does not seem sufficient to merely note certain phenomena. It is also necessary to the understanding of the phenomena that the effect produced be measured, not merely observed. The foundations of physics and chemistry are rooted in the development of mathematical tools. The foundation of cereal chemistry should be rooted in the same place.

The various elements necessary for the quantitative measurement of the effects of mixing speed and dry milk solids were available, but they had to be organized into applicable tools before such measurements could be taken. The assembling of the various and necessary mensuration elements into manageable and useful tools occupied the major portion of the thought in this study. Once the tools were designed, the results were stated in a few paragraphs.

The correlation analyses of the means and their variances showed that each group of combinations had to be analyzed individually, if the original data were to be used. In order to analyze all the data in one variance analysis the original data would have had to have been transformed in such a manner that the correlation between group means and their variances was nonsignificant, as was, fortunately, the case with the combination means and variances within a group.

The noncorrelation of data means with their respective variances is a prerequisite to the proper use of the variance analysis technique. Variance analysis is based on the assumption that the data being analyzed are normally distributed about their true means. A significant correlation between data means and their variances indicates a Poisson (nonnormal) distribution.

The mixing speed-dry milk solids relationship was logarithmically transformed into a linear function such that the logarithmic base was equal to 10. Perhaps some other logarithmic base would have been more exact, but inasmuch as the common logarithms use 10 as their base it was decidedly more convenient and sufficiently accurate for the proper interpretation of the results.

The first derivative indicates the presence and location of a maximum or minimum. The second derivative reflects the shape of the curve representing a function. In this study it measured the rate of change of loaf volume due to changes in dry milk solids content. If there were an increase in the mixing speed tolerance, the rate of change (second derivative) of the loaf volumes would decrease as the dry milk solids content increased and a significant negative correlation should have been obtained. This was not a measure of the increase in fermentation tolerance due to dry milk solids, but of the mixing speed tolerance.

SUMMARY

The object of this study was to determine the optimum mixing speeds for various dry milk solids contents and to determine the optimum dry milk solids content for bread.

Three flours and three mixing machines were used. The flours were from Tenmarq and Chiefkan wheats and a commercial wheat blend. The mixing machines were the newly designed Working, the Swanson-Working, and the Hobart-McDuffee.

Twelve replications of each combination were made in order to more closely confine the variations of the phenomena studied.

The optimum mixing speed, of four flour-mixer groups, decreased slightly as the dry milk solids content increased.

[illegible]

The effect of mixing speed on loaf volume was very highly significant, as was the influence of dry milk solids. The interaction of dry milk solids and mixing speed was highly significant.

The relationship of mixing speed to optimum mixing time was exponential, whereas the relationship of dry milk solids content to optimum mixing time was linear. The loaf volume relationship to both mixing speed and dry milk solids content was quadratic.

The addition of dry milk solids failed to improve the mixing speed tolerance of bread dough.

Optimum mixing speeds were found for different flours on the same mixer and different optimum dry milk solids contents for different mixers using the same flour.

A mixing speed was found for every mixer beyond which there was no appreciable change in optimum mixing time, regardless of the dry milk solids content.

ACKNOWLEDGMENT

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APPENDIX I

Table 36. Observed loaf volumes of Tenmarq-Working group at 0% dry milk solids (in cubic centimeters).

Baking order	Mixing speed 50	75	100	125	150	175	200
1st. day	845	830	840	890	855	865	790
2nd. "	820	795	860	875	870	870	780
3rd. "	860	860	865	865	860	835	740
4th. "	780	795	825	845	860	810	750
5th. "	805	825	845	850	855	830	730
6th. "	825	820	855	855	825	840	730
7th. "	765	755	835	855	800	840	730
8th. "	770	795	765	845	820	815	760
9th. "	670	715	705	740	710	735	705
10th. "	700	690	770	775	750	780	700
11th. "	680	700	710	760	750	740	740
12th. "	705	790	720	755	750	735	700

Table 37. Observed loaf volumes of Tenmarq-Working group at 2% dry milk solids (in cubic centimeters).

Baking order	Mixing speed 50	75	100	125	150	175	200
1st. day	850	860	865	875	890	890	840
2nd. "	810	870	930	930	930	905	805
3rd. "	825	855	840	855	865	830	735
4th. "	800	800	820	825	830	825	745
5th. "	810	820	845	845	875	825	730
6th. "	825	830	850	860	830	820	830
7th. "	840	815	795	865	850	850	840
8th. "	800	770	810	81[illegible]	845	765	725
9th. "	800	785	765	840	830	865	845
10th. "	835	820	855	845	740	830	805
11th. "	885	685	755	740	760	865	720
12th. "	700	68[illegible]	745	760	735	765	725

Table 38. Observed loaf volumes of Tenmarq-Working group at 6% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	855	905	930	900	885	890	835
2nd. "	810	880	945	935	875	900	810
3rd. "	785	855	845	850	855	830	775
4th. "	775	805	800	825	825	865	735
5th. "	815	855	820	850	860	855	765
6th. "	840	860	870	870	855	830	745
7th. "	825	820	800	845	825	825	855
8th. "	795	805	845	805	775	760	735
9th. "	655	650	860	755	700	770	685
10th. "	690	800	895	690	755	700	720
11th. "	715	670	820	770	730	775	755
12th. "	805	770	790	790	810	790	740

Table 39. Observed loaf volumes of Tenmarq-Working group at 12% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	800	820	825	835	865	840	770
2nd. "	815	835	840	855	850	800	765
3rd. "	825	815	830	830	805	720	760
4th. "	765	785	805	775	760	765	755
5th. "	785	775	790	805	835	815	725
6th. "	800	835	835	840	835	840	675
7th. "	835	865	840	800	735	800	795
8th. "	700	730	810	720	650	660	625
9th. "	650	805	835	740	705	790	700
10th. "	650	770	820	645	625	685	650
11th. "	690	730	820	700	690	730	675
12th. "	755	770	730	785	770	765	720

Table 40. Observed loaf volumes of Tenmarq-Swanson Working group at 0% dry milk solids (in cubic centimeters).

Baking order	Mixing speed 50	75	100	125	150	175	200
1st. day	660	710	750	745	755	715	700
	655	710	750	730	740	725	710
2nd. "	710	755	715	755	765	795	780
	700	740	710	775	785	735	735
3rd. "	690	750	740	800	785	775	725
	680	750	740	735	780	760	735
4th. "	730	770	785	750	765	775	705
	740	760	800	775	775	790	720
5th. "	660	770	740	730	755	735	715
	790	750	740	725	740	730	715
6th. "	690	720	730	730	745	735	710
	685	710	745	750	755	755	700

Table 41. Observed loaf volumes of Tenmarq-Swanson Working group at 2% dry milk solids (in cubic centimeters).

Baking order	Mixing speed 50	75	100	125	150	175	200
1st. day	675	750	775	790	790	790	735
	685	750	760	775	795	770	740
2nd. "	710	730	790	785	830	815	730
	725	730	780	775	820	805	735
3rd. "	675	770	820	790	795	795	750
	665	750	805	790	810	785	745
4th. "	605	750	800	775	790	790	725
	700	750	815	760	795	770	710
5th. "	700	730	760	760	765	740	710
	715	715	760	760	775	730	730
6th. "	680	745	730	745	755	740	690
	705	735	745	760	750	725	700

Table 42. Observed loaf volumes of Tenmarq-Swanson Working group at 6% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	720	715	800	795	810	820	710
	725	710	820	795	805	810	720
2nd. "	745	805	800	830	865	825	715
	755	815	820	820	840	820	730
3rd. "	740	800	820	795	850	800	720
	755	795	830	780	845	825	715
4th. "	745	795	845	810	800	775	815
	730	790	860	795	780	775	710
5th. "	695	780	785	775	770	780	705
	685	745	790	785	780	785	700
6th. "	700	770	780	780	745	745	710
	710	775	780	795	735	740	695

Table 43. Observed loaf volumes of Tenmarq-Swanson Working group at 12% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	745	795	800	810	775	760	610
	735	775	820	815	765	750	615
2nd. "	725	830	800	780	815	775	700
	725	815	795	775	800	760	685
3rd. "	720	795	765	800	820	735	640
	720	805	775	810	810	745	625
4th. "	795	805	820	810	745	760	660
	795	790	815	805	750	750	640
5th. "	670	775	775	765	750	770	650
	675	760	780	775	755	755	645
6th. "	725	790	775	795	770	720	645
	725	775	770	780	760	710	645

Table 44. Observed loaf volumes of Tenmarq-Hobart McDuffee group at 0% dry milk solids (in cubic centimeters).

Baking order	Mixing speed 40	70	100	130
1st. day	800	780	840	745
	795	810	805	780
2nd. "	770	790	790	730
	775	775	805	735
3rd. "	730	825	775	785
	730	815	755	770
4th. "	790	780	750	715
	765	780	730	745
5th. "	725	760	725	680
	725	770	715	675
6th. "	715	750	705	655
	695	745	705	675

Table 45. Observed loaf volumes of Tenmarq-Hobart McDuffee group at 2% dry milk solids (in cubic centimeters).

Baking order	Mixing speed 40	70	100	130
1st. day	830	860	855	830
	845	850	850	810
2nd. "	795	805	765	735
	780	820	775	750
3rd. "	840	780	840	780
	830	815	825	800
4th. "	795	805	855	775
	785	805	835	775
5th. "	775	785	695	705
	775	765	700	685
6th. "	690	695	690	670
	665	705	705	680

Table 46. Observed loaf volumes of Tenmarq-Hobart McDuffee group at 6% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	875	885	855	825
	900	875	830	825
2nd. "	810	770	820	705
	795	780	805	705
3rd. "	715	840	855	775
	715	860	850	790
4th. "	785	780	780	690
	790	790	770	705
5th. "	730	725	745	690
	720	730	725	695
6th. "	755	765	775	690
	760	780	770	680

Table 47. Observed loaf volumes of Tenmarq-Hobart McDuffee group at 12% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	845	870	835	865
	840	870	830	855
2nd. "	735	810	775	730
	755	800	775	720
3rd. "	770	760	800	800
	790	740	795	800
4th. "	775	760	830	710
	760	735	815	730
5th. "	750	730	775	670
	745	735	760	680
6th. "	755	745	755	680
	755	740	745	680

Table 48. Observed loaf volumes of Chiefkan-Swanson working group at 0% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	730	720	725	710	705	715	700
	710	720	715	715	710	730	700
2nd. "	715	705	700	700	695	700	675
	715	700	700	705	700	710	680
3rd. "	700	690	695	700	690	690	710
	700	695	695	715	685	690	710
4th. "	[illegible]	720	700	695	690	695	675
	675	710	690	685	680	700	680
5th. "	680	680	660	670	675	755	680
	685	675	660	670	665	655	675
6th. "	[illegible]	735	715	700	730	700	705
	725	725	700	715	720	710	690

Table 49. Observed loaf volumes of Chiefkan-Swanson working group at 2% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	685	735	710	705	685	710	700
	695	720	725	710	685	725	700
2nd. "	680	700	700	690	675	705	680
	690	700	690	675	695	705	690
3rd. "	675	680	680	700	685	675	675
	670	675	700	700	685	680	665
4th. "	675	700	695	675	695	710	675
	690	705	685	690	685	695	675
5th. "	675	680	690	680	665	650	660
	675	670	660	665	670	660	675
6th. "	710	705	710	715	695	695	705
	705	700	705	715	705	695	690

Table 50. Observed loaf volumes of Chiefkan-Swanson Working group at 6% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	690	690	720	695	700	685	685
	700	705	705	710	700	675	695
2nd. "	695	690	675	675	670	695	690
	690	690	690	685	670	695	705
3rd. "	670	680	685	670	665	665	655
	675	675	670	670	670	670	665
4th. "	700	675	655	665	685	675	655
	680	675	635	685	685	690	655
5th. "	650	660	670	670	650	650	685
	650	645	665	670	670	650	650
6th. "	700	695	675	695	685	660	705
	720	695	685	705	690	690	705

Table 51. Observed loaf volumes of Chiefkan-Swanson Working group at 12% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	660	660	685	685	700	655	690
	680	670	675	695	695	675	690
2nd. "	635	645	625	650	680	645	680
	650	650	635	655	670	640	670
3rd. "	650	625	635	645	630	625	625
	650	645	645	645	640	625	630
4th. "	640	635	630	645	665	655	650
	625	625	615	640	665	645	650
5th. "	665	660	655	670	670	665	660
	645	635	650	655	665	670	665
6th. "	650	650	625	650	660	650	635
	645	635	625	655	665	650	650

Table 52. Observed loaf volumes of Chiefkan-Hobart McDuffee group at 0% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	705	705	700	670
	715	690	700	695
2nd. "	685	695	710	680
	670	685	715	675
3rd. "	700	715	710	725
	700	705	730	720
4th. "	710	705	700	695
	710	695	700	690
5th. "	660	700	715	710
	680	690	705	695
6th. "	705	715	730	720
	715	720	720	730

Table 53. Observed loaf volumes of Chiefkan-Hobart McDuffee group at 2% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	700	725	710	670
	700	705	680	665
2nd. "	710	700	700	695
	685	735	690	690
3rd. "	700	700	645	705
	710	690	670	710
4th. "	705	695	635	675
	685	690	695	670
5th. "	680	700	680	690
	695	675	690	690
6th. "	700	690	715	690
	710	700	700	710

Table 54. Observed loaf volumes of Chiefkan-Hobart McDuffee group at 6% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	665	705	680	670
	675	700	680	660
2nd. "	685	695	690	680
	685	700	680	660
3rd. "	725	700	700	670
	715	620	690	675
4th. "	685	680	705	680
	670	690	690	695
5th. "	695	705	685	670
	700	690	680	660
6th. "	700	695	705	725
	700	665	700	715

Table 55. Observed loaf volumes of Chiefkan-Hobart McDuffee group at 12% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	680	650	670	670
	635	650	670	670
2nd. "	635	645	650	660
	625	640	675	655
3rd. "	665	635	690	685
	700	650	665	680
4th. "	625	655	670	660
	645	630	670	675
5th. "	650	650	675	695
	640	655	695	675
6th. "	650	680	675	705
	650	680	705	690

Table 56. Observed loaf volumes of Commercial Mix-Swanson Working group at 0% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	740	720	775	750	765	755	750
	730	725	760	735	770	755	770
2nd. "	765	745	810	750	740	735	735
	770	770	815	760	720	720	715
3rd. "	765	755	775	740	750	720	750
	770	755	780	730	750	725	730
4th. "	760	810	810	800	815	825	750
	750	800	820	810	770	805	760
5th. "	740	800	855	825	850	815	825
	750	775	850	825	850	805	800
6th. "	745	780	800	850	840	850	785
	750	785	790	845	850	840	775

Table 57. Observed loaf volumes of Commercial Mix-Swanson Working group at 2% dry milk solids (in cubic centimeters).

Baking order	Mixing speed						
	50	75	100	125	150	175	200
1st. day	730	770	765	750	760	765	745
	720	750	780	750	770	755	755
2nd. "	810	830	770	770	735	695	750
	785	800	765	740	725	705	740
3rd. "	775	810	840	725	740	710	725
	695	800	825	735	725	715	740
4th. "	790	835	850	830	765	820	825
	770	830	850	775	780	815	835
5th. "	780	830	840	850	850	825	845
	785	810	840	850	875	840	855
6th "	760	815	855	845	860	875	845
	770	820	840	860	855	840	850

Table 58. Observed loaf volumes of Commerical Mix-Swanson working group at 6% dry milk solids (in cubic centimeters).

Baking order	Mixing speed 50	75	100	125	150	175	200
1st. day	720	795	810	730	785	780	765
	710	780	805	795	805	790	760
2nd. "	830	875	795	810	765	740	780
	830	860	815	810	760	750	770
3rd. "	[illegible]	865	800	805	760	755	780
	835	850	815	795	745	765	760
4th. "	855	855	850	865	850	845	860
	850	830	870	870	860	845	840
5th. "	815	845	835	870	880	860	900
	795	825	840	880	875	845	875
6th. "	810	840	860	865	895	870	880
	795	825	855	870	890	890	860

Table 59. Observed loaf volumes of Commercial Mix-Swanson working group at 12% dry milk solids (in cubic centimeters).

Baking order	Mixing speed 50	75	100	125	150	175	200
1st. day	765	770	795	765	790	775	735
	770	785	760	735	790	775	740
2nd. "	845	840	800	760	735	775	755
	810	830	800	775	790	760	745
3rd. "	825	835	780	760	750	790	760
	815	820	775	740	750	780	760
4th. "	810	845	805	830	850	835	855
	835	840	780	845	860	840	845
5th. "	765	795	810	820	835	900	865
	765	795	835	825	845	920	850
6th. "	775	795	825	815	820	865	870
	790	815	815	815	810	860	870

Table 60. Observed loaf volumes of Commercial Mix-Hobart McDuffee group at 0% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	665	680	735	720
	665	685	725	705
2nd. "	675	690	730	710
	685	695	720	715
3rd. "	645	685	705	720
	655	665	695	715
4th. "	640	635	710	700
	645	680	690	690
5th. "	680	675	695	690
	665	685	700	675
6th. "	685	680	710	700
	685	690	710	690

Table 61. Observed loaf volumes of Commercial Mix-Hobart McDuffee group at 2% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	690	715	750	695
	685	725	740	705
2nd. "	705	710	750	695
	725	705	755	680
3rd. "	700	710	710	685
	705	695	710	710
4th. "	700	715	705	710
	700	705	695	715
5th. "	710	700	710	705
	700	710	720	690
6th. "	725	705	705	730
	705	720	705	710

Table 62. Observed loaf volumes of Commercial Mix-Hobart McDuffee group at 6% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	745	770	765	710
	750	760	775	720
2nd. "	730	730	750	755
	735	785	760	755
3rd. "	755	770	735	710
	745	770	745	730
4th. "	755	740	760	725
	745	760	755	705
5th. "	700	750	750	710
	705	760	750	705
6th. "	770	750	750	725
	760	755	745	725

Table 63. Observed loaf volumes of Commercial Mix-Hobart McDuffee group at 12% dry milk solids (in cubic centimeters).

Baking order	Mixing speed			
	40	70	100	130
1st. day	770	790	775	710
	760	785	750	710
2nd. "	765	790	780	720
	755	785	765	700
3rd. "	770	780	780	730
	755	790	790	715
4th. "	775	790	780	740
	780	795	730	725
5th. "	770	775	775	750
	780	765	765	740
6th. "	785	780	775	750
	775	785	770	725